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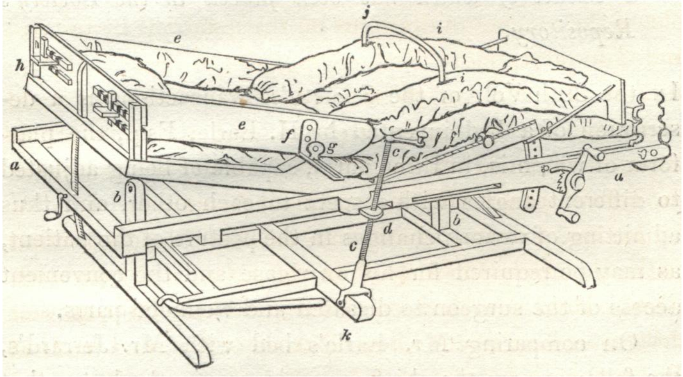
pointed ends of which pass through the bolsters into the mattress. Another advantage of this arch is, that it protects the patient from pressure of the bed-clothes.

The position of a chair is given to the bed by lifting up the head-end of the frame *a*: in so doing, the two arms of the wire *k* drop down and support what now is the back of the chair.



No. XIII.

DIVIDING ENGINE.

The GOLD ISIS MEDAL *and* FIFTY GUINEAS *were presented to Mr.* ANDREW ROSS, *Mathematical Instrument Maker, of* 15, *St. John's Square, for his improved Method of dividing Astronomical and Mathematical Instruments, and for his Circular Dividing Engine. The following Communication has been received from Mr. Ross relative to his Invention.*

AMONG the arts which are necessary to produce accurate astronomical and mathematical instruments, that of dividing, being one of the greatest importance, has, since the time of the earliest astronomers, been practised under various forms in its progress towards perfection.

The first method of which we have any correct account is that by beam compasses; these were employed by Graham, Sisson, and Bird. Graham and Sisson obtained the chord of the arc of 60° from the radius, and completed the number of divisions on the quadrant by bi-, tri-, and quinquesection. Bird computed the chords of such arcs so that when taken from an accurate scale of equal parts, and marked upon the quadrant in their proper order, he obtained the point of 85·20, and then completed the number of divisions by continual bisection.

In the interim, Hook and Roemer practised other methods, widely differing from the above and from each other. Hook's method consisted in racking the quadrant with an endless screw. Several trials of this were made at the Greenwich Observatory, but the method was found defective, and was soon abandoned. The method of Roemer was, stepping a fixed distance throughout the whole of his arc, the distance being so proportioned to the radius of the arc that it was very nearly equal to one of the smaller divisions required ; the total length of the arc in this case being disregarded, as any number of divisions were converted into degrees and minutes by a table calculated for the purpose. This method has defects which render it useless, because any error arising from the inclination of the dotted points or the porosity of the metal, is chargeable upon the whole arc, so that no dependence could be placed on the result; for his table supposes the whole arc to be truly divided.

About the time of Bird, the Duc de Chaulnes published a method of dividing by micrometer microscopes, and several temporary pieces of brass having divisions upon them. Two microscopes, having cross wires in the foci of their eye-glasses, were fixed to a frame, and considered as the points of a pair of beam compasses; these were extended to a diameter of the circle, and two of the temporary pieces of brass were attached to the circle by means of wax underneath the microscopes, so that the divisions bisected the crosses in them; then the circle was moved half round, and, if required, the position of the micrometers and pieces of brass was changed, and the operation repeated until they were diametrically opposite. A cutting-point was then placed over one division and a fixed microscope over the other, so that when any division was brought to bisect the cross in the microscope, the cutting-point made one diametrically opposite. By the process of trial and adjustment with bisections and trisections, the circle was divided into spaces of 10°; then, by obtaining the arc of 9°, by trial in the arc of 180°, the circle can be divided into spaces of 1°, and by similar means into smaller spaces if required.

Ramsden's method of dividing consists in the use of the beam compasses as employed by Bird, and the method of the Duc de Chaulnes combined. The circle is first divided by the beam compasses, and the position of the dots accurately ascertained by means of microscopes, and corrected accordingly, by pressing the dots with the point backwards or forwards by the hand. This method is capable of a great degree of accuracy, but is tedious in the extreme.

The next great improvement was effected by Mr. E. Troughton, in whose hands the art has arrived at a high degree of exactness; but there are various difficulties in the application and construction of the apparatus, which it has been the object of the method now to be described to avoid, by adopting principles perfectly independent of mechanical action, and governed only by vision, aided by the most powerful optical means.

The roller used by Mr. Troughton is wholly rejected, and the apparatus employed is so constructed, that the character of the circle to be divided, whether slightly porous or defective, does not affect the accuracy of the operation. The method of cutting the original divisions is simple and rapid, and in number they scarcely exceed one-third of those employed by Mr. Troughton; thus reducing the labour of observation and computation, while a great practical convenience is gained by making each original division a division of the circle. The construction of the apparatus is firm, and its motion free from elasticity and friction; and when once adjusted, the accuracy of the divisions depends entirely upon the permanence of certain parts, which are so secured as to prevent the possibility of derangement. From the time of cutting the original divisions to the completion of the operation, the circle is free from any attachments of dividing apparatus, and is only viewed through the microscope, so that the ultimate dependence is upon vision.

The apparatus required consists of the following parts. A small circle 10 or 12 inches diameter divided into spaces of 3° 45′, or 96 parts, by the usual dividing engine or by any ordinary means — two micrometer microscopes, represented in Plate I. at *a b*, figs. 1 and 2, which are top and side views — an arc *c c* of the length of 3° 45′ of the circle to be divided — a cutting frame *d e*, and a frame *f f g g*, to support the apparatus. The frame *f g* consists of a bottom and top plate connected by two strong pillars, one of them is represented at *h*, the front one being removed to shew the other parts. In the bottom plate are screwed the nuts *i i*, fig. 2, which form adjustable feet for the frame; these nuts are perforated, and the screws *jj* pass through and fasten the whole securely, after being levelled by the nuts *i* and the level *l*. The upper plate is secured to the pillars *h* by two screws and collets *k m*, moving on *k* as a centre, and adjustable at *m* by the pushing screw *n*, for the purpose of setting the cutting point *o* (which is attached to the upper plate *f*) to cut a radiating division on the circle to be divided: an arc and index at *p*, fig. 1, indicate the inclination given. To the upper plate is likewise attached the hollow centre *q*, fig. 2; in this works a male centre, the flanch of which is seen at *r*, fig. 2, this supports the bar *s s*, which carries the microscopes *a b* and level *l*. The microscopes are secured to this bar by two pulling and two pushing screws *t t t t*, passing through a flanch *v*, and acting in and on the bar *s*. The microscopes are secured to the flanch by fitting into strong tubes *u u*, fig. 2, which are soldered into the flanches *v v*, and when adjusted to distinct vision, can be fixed in that position by the clamping rings *w w*. The handle *x x* for the cutting frame is attached to the perpendicular sling *d*, having a double joint at the point where it is fixed, in order to prevent any unequal pressure from producing a lateral motion of the cutting point; the other end is connected to the upright dovetail slide 34, which forms part of the apparatus for moving the cutting point, and will be found fully described in the account of the dividing engine. The openings are for the purpose of permitting the arc to be viewed through the microscope during its passage over it, and to pass the centre *q* when continued to the cutting frame.

The first part of the process is to make ninety-six divisions at a convenient part of the circle, according to the arrangement of the cutting point and microscope *a*, upon silver dots inlaid for that purpose; and it may be here necessary to remark, that the part of the circle upon which the divisions are to be made must be turned with the most scrupulous exactness; and when the greatest degree of accuracy is required, and microscopes of high power are employed, it will be necessary to turn the circle in its ultimate position, and when the whole is of the same temperature. To obtain the divisions, let the instrument be placed upon its stand, or on a temporary one composed of the same metal as the circle, in its ultimate position, and fix the small circle upon and concentric with the one to be divided. Fix one of the microscopes over the divisions on the small circle, and fix the cutting point over the part of the circle intended for the original divisions. Having determined the zero point of the circle, place the cutting point and microscope in such positions that the first original division shall be the half of $3^0\ 45'$ (by ordinary estimation) from it. The apparatus is then ready, and the whole of the ninety-six divisions may be cut by successively bringing a division on the small circle to bisect the cross in the microscope.

The small circle and microscope may now be removed and the second part of the process performed (which is the same as Mr. Troughton's, except that the first step is a trisection instead of a bisection); but as the process can be carried on by bisection to $11^0\ 15'$, I perform it both ways, the corresponding results being a severe test of the accuracy with which this most important part of the operation is performed, likewise testing the mechanical action of the instrument. The errors being ascertained by bisection, precisely on Mr. Troughton's plan, I cannot do better than quote his description : —

"The circle remaining in its ultimate position, the two microscopes must be firmly fixed to the stand of the instrument on opposite sides, and their wires brought to be bisected by the first or zero division, and the one which should be 180° distant. Now, the microscopes remaining fixed, turn the circle half round, or until the first microscope coincides with the opposite division; and if the other microscope be exactly at the other division, it is obvious that the divisions are 180° apart, or in the true diameter of the circle; and if they disagree, it is obvious that half the quantity by which they disagree, as measured by the divisions of the micrometer-head, is the error of the opposite division, — for the quantity measured is that by which the greater portion of the circle exceeds the less. It is convenient to note these errors + or —, as the divisions are found too forward or backward according to the numbering of the degrees; and for the purpose of distinguishing the + or — errors, the heads are numbered backwards and forwards. One of the microscopes remaining as before, remove the other to a position at right angles, and considering for the present both the former divisions to be in their true places, examine the others by them, *i. e.* as before, try by the micrometer how many divisions of the head the greater half of the semicircle exceeds the less, and note half the quantity + or — as before; and do the same for the other semicircle. One of the micrometers must now be set at an angle of 45° with the other, and the half differences of the two parts of each of the four quadrants registered with their respective signs. The microscopes must now be placed at the distance of 22° 30′, and the half differences of the parts of all the arcs of 45° measured and noted as before, thus descending by bisections to 11° 15′. During the whole of the time that the examination is made, all the divisions excepting the one under examination are for the present supposed to be in their true places, and the only thing in this important part of the business from first to last is to ascertain, in divisions of the micrometer-head, how much one of the parts of the interval under examination exceeds the other, and carefully to tabulate the half of their difference.

"The foregoing examination furnishes materials for the construction of the table of half differences, or apparent errors. The first line of this table, with a distance of 180°, is the real error of 180°. The second course, with a distance of 90°, makes the series of half differences of 90° and 270°.

3d, with a distance 45°.	4th, with a distance 22° 30′.	5th, with a distance 11° 15′.	
45°	22° 30′	11° 15′	191° 15′
135	67 30	33 45	213 45
225	112 30	56 15	236 15
315	157 30	78 45	258 45
	247 30	101 15	281 15
	292 30	123 45	303 45
	337 30	146 15	326 15
		168 45	348 45

"The table of half differences or apparent errors, just explained, furnishes data for computing the table of real errors. The rule is this: Let *a* be the real error of the preceding division, and *b* that of the following one, and *c* that apparent error taken from the table of half differences of the division under investigation; then $\frac{a+b}{2} + c =$ its real error. Or it may be necessary to say the same thing less concisely. If the real error of the preceding and following divisions are both + or both —, take half their sum and prefix thereto their common sign; but if one of them is + and the other —, take half their difference, prefixing the sign of the greater quantity. Again, if the apparent error of the division under investigation has the same sign of the quantity found above, give to their sum the common sign for the real error; but if their signs are contrary, give to their difference the sign of the greater for the real error. I add a few examples.

EXAMPLE I.

For the error of 90°.

Real error of zero	0·0
180	— 6·9
Half sum or difference	— 3·4
Apparent error of division under trial	+12·2
Real error	+ 8·8

For the error 135°.

Real error of 90	+8·8
180	—6·9
Half difference	+0·9
Apparent error of division under trial	—8·9
Real error	—8·0"

In this description I have made the necessary alterations from Mr. Troughton's account, suitable to the different arrangements of the original divisions. I now pass on to describe the other examination of the original divisions, beginning with a trisection, which is thus performed. Take the measure of the arc from 0° to 120°, compare this distance with the arc 120° to 240°, and note the measure + or — in value of divisions of the micrometer-head. Compare also the arc from 240° to 360° with the first arc, and note as before which is the longer of the two; then the difference of the first arc from the mean of the three is the error of 120°, giving it the proper sign to express its position with respect to the zero point of the circle.

EXAMPLE.

$$\begin{array}{rcrl}
0 \text{ to } 120 & = & 1 & \\
120 \text{ to } 240 & = & 1 + 10{\cdot}9 & \\
240 \text{ to } 360 & = & 1 + 2{\cdot}5 & \\
\cline{3-3}
 & & 3)3 + 13{\cdot}4 & \\
\cline{3-3}
 & & 1 + 4{\cdot}5 & \text{mean.} \\
 & & 1 \phantom{+ 00{\cdot}0} & \text{first arc.} \\
\cline{3-3}
\text{Real error of } 120 & = & - 4{\cdot}5 & \\
\cline{3-3}
\end{array}$$

The error of 240° can be obtained from the same data; but to avoid error in prefixing the signs, it will be more secure to obtain it by bisection, as the real errors of 0° and 120° are known: then the courses for examination by bisection are conducted precisely as I have quoted from Mr. Troughton's account, and are as follow: —

1st, with a dist. 120°.	2d, with a dist. 60°.	3d, with a dist. 30°.	4th, with a dist. 15°.	5th, with a distance 7° 30′.		6th, with a distance 11° 15′.		
240°	60°	30°	15°	7° 30′	187° 30′	11° 15′	18° 45′	26° 15′
	180	90	45	22 30	202 30	33 45	41 15	48 45
	300	150	75	37 30	217 30	56 15	63 45	71 15
		210	105	52 30	232 30	78 45	86 15	93 45
		270	135	67 30	247 30	101 15	108 45	116 15
		330	165	82 30	262 30	123 45	131 15	138 45
			195	97 30	277 30	146 15	153 45	161 15
			225	112 30	292 30	168 45	176 15	183 45
			285	127 30	307 30	191 15	198 45	206 15
			315	142 30	322 30	213 45	221 15	228 45
			345	157 30	337 30	236 15	243 45	251 15
				172 30	352 30	258 45	266 15	273 45
						281 15	288 45	296 15
						303 45	311 15	318 45
						326 15	333 45	341 15
						348 45	356 15	3 45

It will be seen that the first column of the last course is the same as in the examination by continued bisection; and these divisions can be observed with the same fixing of the microscopes. The divisions may be marked according to their angular value with a fine-pointed black-lead pencil, sufficiently small and near to them to be in the field of the microscope at the time of observation, so that the possibility of mistaking the division to be examined is thereby prevented. The next step is to compute the real errors; and here, to avoid mistake, I form the table precisely as represented in the examples, and, after comparing the results of the two series of examinations, I extract a table of real errors in the order of the original divisions.

The errors of the 96 divisions being known, it now remains to cut them in their true places, also the whole of the divisions of the circle to the value of 5′. The apparatus employed in this part of the process is represented in figs. 1 and 2; but previous to describing this operation I shall particularly explain the nature of the divisions on the arc *c c*.

From a series of observations made upon several instruments, to determine the errors of the ordinary dividing engine, it occurred that in large arcs the error varied from 5″ to 17″; but on the examination of some smaller arcs, the mean error was about 4″; and as the linear value of this angular error will be directly proportional to the radius, it follows that if an arc, as in Plate II fig. 12, is divided into angles at a short radius r, so that, when placed at a longer radius R, a point moving round the centre c and passing over the divisions on that arc placed at R makes equal angles *a a* when in coincidence with each division, the angular error in the equality of those spaces will only amount to $\frac{r}{R}e$, e being the angular error of the part of the dividing engine used in cutting the divisions at the short radius; and if this operation is successively repeated by attaching the arc to the engine plate and fixing a microscope over the divisions, instead of using the screw as in the first instance, the utmost limit of accuracy that the motions of the cutting frame and vision, assisted by most powerful means, is capable of, can be obtained. In applying this principle to obtain the divisions on the arc, let A, Plate II fig. 11, be the centre of the circle to be divided, A M the shorter radius of the original divisions, M the micrometer from which the apparent errors were registered. This microscope is attached to an arm, *b m*, and moves on a centre *c* (the same as marked *s s* and *q* in fig. 1 Plate I), and *m* is the other microscope observing the arc.

Let M *b* be the half of an original space, then *c* will be the angle when the microscope M is observing the original division in its extreme position, and its opposite angle being equal, it will also be the extreme angle on the arc; to obtain which there is the triangle A *b c*, with the angle at A given, being the half of an original space $= 1^{0}\ 52'\ 30''$, and *b c* may be ascertained according to convenience, or the determined ratio of the radii; and $\mathrm{A}\,c = b\,c + \mathrm{A\ M.}$, then $b\,c : \sin \mathrm{A} :: \mathrm{A}\,c : \sin b \therefore \sin b = \frac{\sin \mathrm{A}.\ \mathrm{A}\,c}{b\,c}$ and $c = 180 - (\mathrm{A} + b)$, and this is the form for computing all the angles on the arc; for as the instrument is divided into spaces of 5′, the angle at A is successively the preceding angle $-5'$, and the sides A*c* and *bc* are constant.

It will now be seen, that the length of the original divisions must be equal to the versed sine of the angle *c* to the radius *b c* or *c* M, and that they should be truly radiating. It will also be observed, that as the error of the division is taken at its shorter radius, it will be greater as the radius is increased, and likewise that, at the time of observing, the micrometer was a tangent to the circle; but when the microscope is observing the extreme division on the arc, and the original division is brought in the field of the other microscope, it is observing a different part to that used in obtaining the error, and the micrometer is not a tangent to the circle. These circumstances shew the necessity of cutting the original divisions in their true places before dividing the whole circle; for, if the erroneous divisions were used, as in Mr. Troughton's plan, it would be necessary to apply a correction at several stages of the original space, according to the extent of the real error and the angle *c;* which would be rather a complex operation and introduce the liability of mistake.

The next step, therefore, is to cut the original divisions in their true places, which is performed by using the cutting frame the same as in cutting them originally, and adjusting the point to cut a radiating line by making long opposite divisions on thin temporary pieces of brass, and to observe the error at each end of one of them, and incline the point by the screw *n*, fig. 1, until the errors are alike, or until there is no error, when one of the microscopes is moved to each end of the division. Then fix the cutting frame at the nighest convenient distance, and also fix the micrometer which was used in obtaining the apparent errors to the upper plate of the frame of the apparatus by a temporary arm, and previous to cutting each division, place the micrometer-head at the real error of the division under the microscope + or — as extracted from the computations. This operation being completed, it gives additional satisfaction to examine the divisions again, and if correct, the whole divisions may be cut on the circle.

The apparatus complete, as represented at figs. 1 and 2, is used in this operation, and is to be placed on the stand in such a position, that the distance between the centres A *c* shall be as nearly equal to that used in the computations as ordinary means will command. The cross is now to be taken out of the microscope *a*, and a thin plate of metal put in its place, with a small hole perforated, such that the image of the divisions will occupy about three quarters of its diameter. Then, to bring the various parts into adjustment, first make the surface of the circle perfectly level, and the centre of the apparatus perpendicular by the level *l* attached to the bar *s*; this will preserve distinctness during the passage of the microscope *a* over the circle, while the microscope *b* is passing over the arc. The next adjustment is to make the centre of the circle the centre *q* and the middle of the arc *c* in a line, and that the microscope *b*, in moving between the extreme divisions of the arc *c*, shall move the microscope *a* accurately over an original space. To effect this, it is necessary to have a boundary line described to the original divisions, which should be made, at the time the circle is turned, with a fixed point so that it shall be perfectly concentric, and the original division should be made to intersect this circle. Half way between any of the original divisions, there should be a division which is to be made at the time of cutting the original divisions, and the error of it obtained at the time the original divisions were verified; then having placed the microscope *b* over the divisions on the arc *c* (which should have its middle division cut at the time of cutting the other divisions) bring the hole in the microscope *a* over an original division at the intersection of the circular line. The circle remaining stationary, move the microscope to the next original division, and observe if the intersection of the circle and original divisions is in the hole in the microscope; if not, move the circle and microscope, and repeat the operation until the intersections pass the centre of the hole in the microscope in its course over the circle. The circle remaining in this position, place the microscope *a* over the division between the original divisions, allowing for its error; then adjust the microscope *b* for its cross, to be bisected by the middle division on the arc.

The microscope *b* is now to be placed at an extreme division on the arc, and an original division brought into the other microscope, then move the bar *s* until the other extreme division of the arc bisects the cross, and observe if the original division bisects the hole in the other microscope; if not, the microscope *a* must be moved to or from the centre of the circle, as the microscope is found to measure too small or too great a space; for, the original divisions being radiating, the nearer the microscope is moved to the centre of the circle, the smaller will be the linear value of an original space, and *vice versâ.* These adjustments must be carefully performed, and verified at intervals, until the angle moved through by the bar *s*, governed by the arc *c*, coincides accurately in the microscope *a* with an original space, and the middle divisions of the arc and original divisions agree with the cross and hole in the microscopes at the same time. The apparatus is now ready to cut divisions; to perform which, bring the micrometer-head of the microscope *a* to zero, and let the cross in the microscope *b* be bisected by an extreme division on the arc *c;* then bring the zero original division to bisect the hole in *a.* It will be recollected, that the zero original division was placed half an original space from the real zero; and when the apparatus is placed as above directed, the cutting point will be found half an original space from the original division,—so that the zero division of the circle will be in its right position. The microscopes and circle being in this position, let a division be cut, then move the bar *s* by the pushing screw *y*, fig. 1, until the next division on the arc bisect the cross, then move the circle by its tangent screw until the original division bisects the hole, and cut again. Proceed in this manner through the whole original space, then leaving the circle in the position in which the last division was cut, move the bar back to the first division on the arc again, and observe that the next original division now bisects the hole in *a;* then proceed as before to cut the whole of the divisions in that space, and the same for the whole of the circle. It may be observed, that a test of the permanence of the adjustments of the apparatus is formed at every space by the original division bisecting the hole in *a*, when the microscope *b* is moved back to the beginning of the arc.

The long handle *x*, fig. 1, which moves the cutting point, prevents any partial expansion in the apparatus; and for this purpose the whole may be enclosed and viewed through a plate of glass at the top. A narrow slit will be sufficient for the handle to pass through. This handle *x* serving the same purpose as the connecting bar 25 in the engine, Plate III fig. 1, and is jointed like that to the vertical slide 34 of the moving apparatus; but there is an arm 2 attached to *x*, which projects under the frame *e* to lift the cutter off the work, when the bar *x* lowers; therefore the action of the lever 22 Plate II fig. 1 will be reversed when the point is cutting the divisions, by which arrangement the bar *x* will be raised while making the cut, and lowered to return.

The best light I have found to be an Argand lamp, placed outside the apartment in which the operation is performed, and refracted or reflected through a hole to the divisions. This will likewise give sufficient light in the room to move the adjusting screws and cut the divisions. These arrangements prevent the possibility of partial expansion from the heat of the light, and enclosing the apparatus prevents the same from the proximity of the body, the breath, or the heat of the hand; and as this is the only thing that can affect the accuracy of the operation in this method of dividing, it must be guarded against in every direction, which the construction of the apparatus greatly facilitates. It may here be noticed, that the effect of partial expansion must be observed in the second part of the process, when the apparent error of the large arcs is taken. For this purpose there should be several thermometers applied at various parts of the circle; and before observing, it should be ascertained that they all indicate the same temperature. This is of the greatest importance, as the errors obtained by trisection, if this is not scrupulously attended to, will not agree with those obtained by bisection; but in the smaller arcs it is only necessary that they individually should be at the same temperature.

The microscopes I use have the focus of the object-glass about ten times the distance of the plane of the divisions from it, and the screw has 100 threads in an inch; this is moved by a micrometer-head having 100 divisions, so that by this arrangement the value of each division is $\frac{1}{10000}$ of an inch. The cross wires are placed at the angle 20°, and, with a little experience and fine optical powers, the bisection of the cross by a division may be observed within this value.

The method of filling up an original space by copying an accurately divided arc by microscopic means, may be applied in various ways. I have had a frame rolling on the arc of the circle carrying the microscopes, and the cutting frame and arc to be copied on the stand. I have also attached the microscopes to a bar having a Y at one end bearing on a cylinder on the centre of the circle: but these modes are objectionable, as they encumber the circle to be divided.

This method of dividing can with facility be applied to linear instruments. For this purpose a plane of brass, or cast iron, about 8 inches wide, and of the requisite length, having its edges perfectly straight, is necessary to support the apparatus, which in this case is to move along the bearer or plane, being guided in its motion by studs rubbing against the edge and kept in contact by a spring and rollers acting on the other edge. The series forming the original divisions (supposing a scale of inches and parts) is $\frac{36}{3}=12$ in., $\frac{12}{2}=6$ in., $\frac{6}{2}=3$ in., $\frac{3}{2}=1{\cdot}5$ in., the errors of which are to be taken and computed as directed for circular dividing, and these can be verified by bisection, down to 4·5, for $\frac{36}{2}=18$ in., $\frac{18}{2}=9$ in., $\frac{9}{2}=4{\cdot}5$ in. The spaces of 1·5 being filled up with equal and parallel divisions, the angles on the arc can be obtained by making the differences of the tangents to the radius c M, Plate II fig. 11, equal: for, suppose the scale to be divided into tenths of an inch, then the first tangent from the middle of the arc $=\frac{1{\cdot}5}{2}$ in. $=\cdot 75$ in.; and the tabulated natural tangent of the extreme division on the arc will $=\frac{\cdot 75}{c\,\mathrm{M}}$, and the tabulated natural tangent of the other angles will be successively *the preceding linear value on the scale* $-\frac{\cdot 1}{c\,\mathrm{M}}$. The original divisions are to be cut in their true places, precisely as described in circular dividing; and in cutting the whole of the divisions, the only difference is, that the apparatus is movable instead of the instrument to be divided.

By this system accurately divided scales of any description can be obtained; and it appears peculiarly adapted for those of zenith sectors, the application to which must be sufficiently obvious.

Description of the Dividing Engine.

Since the construction of the endless screw-dividing engine, by Ramsden, there has been but one improvement made of any consequence, viz. that of Mr. Allan, which appears well calculated to correct errors arising from the gradual increase or decrease of the size of the teeth in the circle; but where the asperities are to be removed by such an obtuse cutting angle as that presented by a serrated cylindrical screw, the pressure required is too great to be compatible with those delicate operations which are necessary to obtain the accuracy which such a machine ought to possess. There are other difficulties, arising from the heterogeneous nature of even the best steel that can be obtained for forming the screw, likewise the porosity and want of homogeneity in cast materials for forming the circle.

These considerations, which were deduced from a practical acquaintance with the subject, led me to a mechanical modification of the previously described primitive method of dividing, of which the engine now to be described is the result.

The principal mechanical action, or that which regulates the motion of the circular plate, is the reverse of the endless screw, which acts by driving. In this engine, a rotary motion is supplied by an independent apparatus, and the circle is stopped at its precise angular position by the contact of plane and spherical surfaces of hardened steel; their truth being ascertained by preliminary experiments to be far within the limit of admissible error.

The machine is represented at fig. 1, Plates II. and III. In Plate II. fig. 1, is a top view of the engine, and in

Plate III. is a sectional view. 1 1 is a frame of cast iron, on which the engine is mounted; 2 2 the hollow centre, screwed to the frame by the flanch 3 3; the axis consists of two similar cones 2 2, which are screwed to the circular plate *a a a a* by its flanch. Around the circle are screwed 48 cocks *b b*, &c., having capstan-headed screws *c c* (shewn half the real size in figs. 2 and 3, Plate II.) passed through them parallel to the plane of and tangent to the circle. The ends of the screws are hardened and ground flat and square to the axis; this is effected by screwing them into a piece of brass about one inch and a half in diameter, whose thickness is rather less than the length of the screw. This must previously have its surface turned flat upon a true screw arbor, then the projecting end of the screw is to be ground off upon a flat metal surface until it is level with the turned surface of the brass. These screws may be fixed in any position by the tightening screws *d*. The weight 4 on the lever 5 supports so much of the weight of the circle as to let it move pleasantly. At one end of the stand of the machine is a sliding plate which carries the worm *e e*, it is movable by the screw 7, for placing the worm in or out of gear with the cocks on the circle. The plate is brought into its precise position by three steady pins 9 9, and secured by four binding screws 10 10; two of them, with one steady pin, go in underneath, and are not shewn. The distance between the shoulders of the screw 7 being greater than the thickness of the standard 8, is for the purpose of preventing strain upon the steady pins. The worm *e e*, or one single revolution of a square-threaded screw moving on a horizontal axis, having the distance between its threads equal to the distance of the ends of the tangent screws *c c* &c. on the circle, is pierced, parallel to its axis, with 90 holes, to receive capstan-headed screws *f*, fig. 2, Plate II., with spherical ends,—these have also tightening screws *g*. The pivots of the axis are turned with a screw tool, so as to have rings on them, and the bearings have corresponding rings within, this prevents end shake; one of the pivots is seen in fig. 6, Plate II. On the outer rim of the circle, a groove *h*, fig. 3, is turned, in which a slight catgut *i i*, fig. 1, passes round, moving over pulleys *jj*, and then under the weighted pulleys *k* and *l* at each side; the weight *k* being superior, always brings the screws on the circle in contact with those in the worm *e*. The gut *i* rises from the weight *k* to the clamp *m*, where it is bound fast; it then passes above the machine to a notch *n*, and then down to the pulley *b*, in an endless band, of such a length that when one weight is up, the other is down. When the weight *k* is down, the clamp *m* is to be loosened and *k* raised, this lets the weight *b* run down the clamp; *m* is then to be tightened, and the whole is ready for action again. The portion which passes over the machine is broken away, that it may not interfere with the view.

The four pillars 11 11 support the triangular bar 12 12, on which slides a saddle 13, to which is appended the cutting apparatus, of which fig. 6 is a front view, and fig. 7 is a side view; 14 14 is a sliding plate to adjust the height of the swing frames 15 16: the part 17, in which the cutting point is fixed, may be secured at any inclination by the screws 18 18. The pedestal 19 supports the moving apparatus, fig. 8 shews it partly in section, and in Plate II. fig. 7 is a front view; 20 20 is a dovetail sliding bar, with a standard 21 rising from the middle; 22 is a forked lever, the prongs of which embrace the standard to give an alternate motion to it and the bar 20: the diameter of the standard is about two-thirds of the opening in the forked lever. Fig. 8, Plate II., shews the frame in which the bar 20 slides with a stud 23, on which the lever 22 moves. To the sliding bar 20, Plate III., is jointed a vertical sliding frame 24, to the sliding bar of which is jointed the adjusting bar 25, which connects this moving apparatus to the swing-frame 15 ; the vertical sliding frame 24 is also jointed to the sliding bar 20, and connected to the standard 21 by an adjusting bar 26, in order to give that inclination to the sliding frame 24 which prevents motion in the swing frame and cutting point during the rise or fall of the connecting bar 25. To the swing frame 15 is screwed a double joint 27, shewn fig. 7; in this one end of the connecting bar 25 moves, concentric with the axis of the cutting frame 16 but quite free from it. Upon the bar 25 is mounted a frame 28, figs. 1, 7, and 9, in which a bar moves by the adjusting screw 29; at the bottom of this bar is a square opened across, to which another small bar 30 is screwed; and from the frame 16 projects a cylinder 31, fig. 6, which passes through the opening and rests upon the bar 30, so that when the bar 25 rises it lifts the cutter. 32, fig. 9, is a balance-weight. A lever 33 is jointed on the sliding bar 20, shewn in figs. 8 and 10, the long arm passes under the upright sliding bar 34 in the frame 24, and the short arm terminates in an inclined plane, which rises in the space between the fork and the standard 21; then, during the motion of the fork through the space which is not occupied by the diameter of the standard, it presses the short end of the lever down, and, by the alternate motion, permits it to rise before the inner sides of the fork act upon the standard 21.

Now, to exemplify the method of using this apparatus, let the handle 22 be in the dotted position nearest the machine, Plate II., then the short end of the lever 33 will be depressed and the slide 34 elevated, and with it the bar 25 and frame 28, and let the cutting point be lifted off the work to be divided; then move the handle 22 gently from the machine, this will permit the short end of the lever to rise between the fork and the standard, and the long end will be depressed, and with it the slide 34 the connecting bar 25 and the frame 28, until it has left the cutting point resting on the work; the inside of the fork will now be nearly in contact with the standard, move the handle farther, and this will press forward the slide 20 the connecting bar 25 and the swing frame 15, which will draw the swing 16 and cutting point along with it, and make a division; then reverse the motion of the handle, and the fork will press the short end of the lever down, this will raise the slide 34, and with it the cutting point from the work; the other inside of the fork will now be nearly in contact with the standard, move the handle farther, and the slide 20, with the connecting bars and cutting point, will be brought back ready to cut another division. The lengths of the divisions are regulated by a cross piece 36, figs. 8 and 10, on the top of the standard 21, coming in contact with the end of the screw 35 and the edge of the circular steel plate 37. The short divisions are limited between the ends of the screw 35 and the edge of the steel plate, and the longer divisions are given by notches in the steel plate, which lets the stop 36 move so much farther, and these notches are presented in the proper order by a ratchet-wheel 38 (which moves on the same centre-pin as the steel plate shewn in fig. 8,) and a click 40, which is connected to the forked lever 22 by an adjustable arm and stage 39, supported by three pillars, shewn separate in Plate II. fig. 8; this click is kept in contact with the teeth of the ratchet-wheel by a slight spring, so that the same motion which operates in cutting the divisions constantly regulates the lengths of them. When cutting from the centre, the lever represented fig. 12 is to be used instead of that previously described; and when the long and short divisions are on the outer circumference, the steel plate 37 and screw 35 change places. By this method of cutting the divisions, the body may be at some distance from the cutting point and circle, which prevents the effects of partial expansion in the dividing apparatus and instrument to be divided, which must necessarily occur in the course of an operation in the ordinary method, from respiration and the heat of the hand. It also cuts the divisions uniformly straight and equable, likewise obviates the necessity of circumscribing the divisions with a deep coarse line, thereby considerably reducing the liability of breaking the point, which is of great importance in the use of the diamond.

The lever to which is attached the handle *w*, Plate II. regulates the motion of the worm and circle; this lever passes through the pedestal and moves upon a centre-pin within it; to the short end of the lever *z* is jointed the connecting bar *x x*; near *z* is an adjusting screw, by which the motion of the lever and bar is limited; the other end of the bar *xx* has a double joint, by which it is connected to the arm *y*, figs. 5 and 6 Plate II.; the opposite arm 44 carries a spring click; these arms move on a hollow axis concentric with the worm, but independent of it: a section of this is shewn fig. 6. The axis of the arms *y* 44 is supported by the standard 47, which is screwed to the sliding plate 6 6, which carries the worm; the spring click moves the ratchet-wheel 45 attached to the worm, and is stopped at this end of the bar by the arm *y* abutting against the stud 46, fig. 5, and is limited in its motion the other way by the screw at *z* stopping the motion of the lever. A spring 41 faced with leather presses against the catgut *i* and rim of the circle; this prevents the motion of the circle until the spring is removed out of contact by the pressure of the screw 42. Now, to trace the operation of moving the circle, let the handle *w* be in the position represented in Plate II., then move the handle from the machine, this will move the bar *x x* the contrary way, and will move the arm *y* from the centre of the machine until it stops against the stud 46; this motion will have brought the arm 44 and spring click toward the centre of the machine, and have moved the ratchet-wheel and worm round, and consequently moved the screw in the worm out of contact with the screw in the circle; the handle *w* is now to be moved back, when the click passes over the teeth on the ratchet-wheel, and the worm remains stationary, the screw 42 will then come in contact with the spring 41; now press the handle a little further (as represented by the dotted lines, Plate II.) and this will remove the spring out of contact; the weight *k* will immediately give motion to the circle and bring it in contact with the worm. In removing the spring out of contact, the power should be gently applied, so that the circle slides round and does not drop with any violence against the screw in the worm; and when the contact of the screws is complete, the spring should be kept out of contact with the circle, then at the instant of cutting the division, the circle is under no influence but the constant force of the weight *k*. The length of the screw at *z*, with several holes in the bar *x* to joint the bar to the lever, afford convenience to escape over as many teeth of the ratchet-wheel 45 as may be required.

In fig. 1, Plate II., is an iron segment 48, supported on three arms projecting from the iron stand 1 1, upon this are fixed three pillars 49, 50, 51, two of them hold micrometer microscopes, 52, 53, the other 51 holds the screw 54, which acts against the piece fig. 9 when it is screwed on the circle, and the worm *e e* is drawn out of gear. This is used when dividing vernier scales, these being obtained from divisions made by the engine upon the silver ring, by means of the micrometer microscope.

This description has chiefly applied to the construction of the machine for transferring divisions by the mechanical action of contact; it now remains to be described how the various parts are regulated, according to the principles laid down in the primitive method of dividing.

Corresponding to each cock *b* on the circle is inlaid a small circular disc of silver to receive original divisions. These are to be made, and the errors of them obtained, as directed in the primitive method of dividing; then the ends of the screws *c* on the circle may be adjusted to their true position, by fixing the microscope placed at zero over the original division zero, when a screw *c* on the circle is in contact with one in the worm *e*, then move the worm one revolution, and the next screw in the circle will be in contact with the same screw in the worm, and the next original division will be under the microscope; place the micrometer-head at its real error, and move the screw *c* on the circle until the division bisects the cross in the microscope, and repeat the same operation with the whole 48 screws. The means for adjusting the screws *f* in the worm are similar to those in the primitive dividing for filling up the original space; but in this case the constant sides of the triangle are different.

Let *c*, fig. 4, Plate II., be the centre of the dividing engine, cb its radius, and $ba = \frac{bc}{m}$, then as before $bd =$ half an original space, and as the angles are to be $5'$ (this being the angle given by the number of screws, and affording all the variety in dividing astronomical and mathematical instruments) the angles at c will be successively $3^0\,45' - 5'$, $(3^0\,45' - 5') - 5'$, &c., then $(ac + bc) : (bc - ac) :: \cot\frac{c}{2} : \tan\frac{a-b}{2} \therefore \tan\frac{a-b}{2} = \frac{bc-ac}{ac+bc}\cot\frac{c}{2}$, then $\frac{a-b}{2} + \frac{a+b}{2} = a$, and $180 - \left(\frac{a-b}{2} + \frac{a+b}{2}\right) =$ the external angle at a. Then, for the most convenient form of computing the angles, this reduces to $\frac{bc-ac}{ac+bc}.\cot\frac{c}{2} = \tan\frac{a-b}{2}$, and $90^0 + \frac{c}{2} - \frac{a-b}{2}$ = the angle to be cut upon the arc, fig. 10, Plate II.

It is necessary that the boundary lines on the scale should be described while revolving with the engine, and that the first and last division should intersect these lines; the dividing point should also be adjusted to cut a radiant line. This affords the method of making the two centres and the middle of the arc in a line when placed at its longer radius. For this purpose it is only necessary to make the intersection pass the centre of the hole in the microscope. The other microscope is now fixed over the original divisions, and the one over the arc must be adjusted until the space between the extreme divisions on the arc equals an original space, as directed in the primitive dividing. The screws *f* in the worm *e* are now to be adjusted until each division on the arc bisects the hole in the microscope, when the screw in the worm is in contact with the one on the circle. The engine should now be worked round several times, and the adjustments repeated at intervals, until they are found to be constant and perfect. Thus, by the most delicate operations, the machine is rendered capable of moving through its angular spaces with a great degree of accuracy and certainty; for without very minute examination and adjustment, the machine can be regulated within 2″; and from observations I have made, with delicate adjustment and minute observation, the contacts may be made to a division of the micrometer-head, which is $\frac{1}{4}$ of a second.

There are two sources of error in this machine: 1st, the difference of expansion in the worm and stand, the worm being of bell-metal and the stand of cast-iron, then the worm expanding about $\frac{1}{1000000}$ part of its whole length for each degree of temperature, which is about $\frac{1}{4}$ of a second, and the expansion of cast-iron about $\frac{2}{3}$ that of bell-metal; then the difference $\frac{1}{4}'' - (\frac{2}{3} \text{ of } \frac{1}{4}'') = \frac{1}{12}''$; so that it is necessary to adjust the worm in a mean temperature, then this source of error will not affect the accuracy of the engine in any material degree when the temperature is between 35^0 and 75^0 of Fahrenheit. The other source of error is, that the ends of the screws on the circle are not perfectly square to their axes; and as the spherical ends of the screws in the worm do not come in contact with the flat ends of those in the circle at the same point in every contact, but differ nearly as the secant of the angle (this at the extremes is about $\frac{1}{30}$ of an inch) therefore, any difference in the inclination of the ends of the screws on the circle will produce error. This error can be halved by adjusting the screws on the circle against that screw in the worm which comes in contact at the mean point; this occurs at the eleventh screw from the extreme; then by removing the microscope so that an extreme screw comes in contact with the screw on the circle, when the original division is under the microscope, the amount of this error can be obtained. In this case, in some places, it amounts to 1″; so that if all the greatest errors occur at the same time, and all the same way, the error will be about 3″.

The usual method of centering the instruments to be divided on the engine is very defective, for it often happens that the axis of motion of the instrument is not truly in the centre of their permanent fittings; and this, with other causes, produces a disagreeable eccentric error in circular instruments, though really of no consequence where there are two verniers, for the angle observed is an angle within a circle, and is measured by half the sum of the intercepted arcs, therefore half the sum of the opposite readings will be the true angle; but in instruments having but one vernier, and more particularly in sextants, this produces serious error, for I have seen eccentric error in circular instruments which might produce an error in a sextant to the extent of 3′. This led me to devise a method of centering, whereby the axis of motion of the centres of the instrument may be made in a line with the axis of motion of the centres of the dividing engine, and is thus effected. Suppose the instrument to be a sextant, then, to the flanch, figs. 2 and 5 Plate III., of the male centre is screwed or cemented a double dovetail slide *q r*, figs. 2, 3, and 4, the slides at right angles, with drawing screws *s s* and spiral springs *t t* to each slide, and on the upper slide is made a dot. The instrument is laid upon the centre of the engine-plate, and over the dot is fixed a microscope, Plate III. fig. 11, with cross wires. The male centre *o* is then made to revolve, and the slides adjusted until the dot is perfectly stationary: the engine-plate *a* is then made to revolve, and the instrument is moved by the pushing screws *u u* and opposite spring slides *v v*, fig. 5, until the dot is again stationary during a revolution. Thus, by the first adjustment, the dot is in the axis of motion of the centre of the instrument, and by the second the same is made in the axis of motion of the dividing engine. For other instruments there are four adjustable dots placed at a convenient distance from the centre, and these are made to pass a wire in the microscope while revolving on its own centre likewise, when on the engine. This affords a great convenience in circular instruments, and is an improvement of considerable importance in sextants.

No. XIV.

IMPROVEMENT IN THE MICROSCOPE.

The LARGE SILVER MEDAL *was presented to Mr.* CORNELIUS VARLEY, 1, *Charles Street, Clarendon Square, for his Microscope peculiarly adapted for the examination of live aquatic objects, and his Apparatus for catching and retaining them.*

VERY early in life I was employed in making microscopes, and the lenses for them: these I always polished on bees'-wax, hardened either by Tripoli or red oxide of iron, a composition greatly superior to cloth, which still continues to be generally employed for that purpose; and, notwithstanding the advantages of using bees'-wax have been freely communicated to opticians, it has not yet got into common use in the process of polishing lenses.

On this account, and the defective adaptation of most